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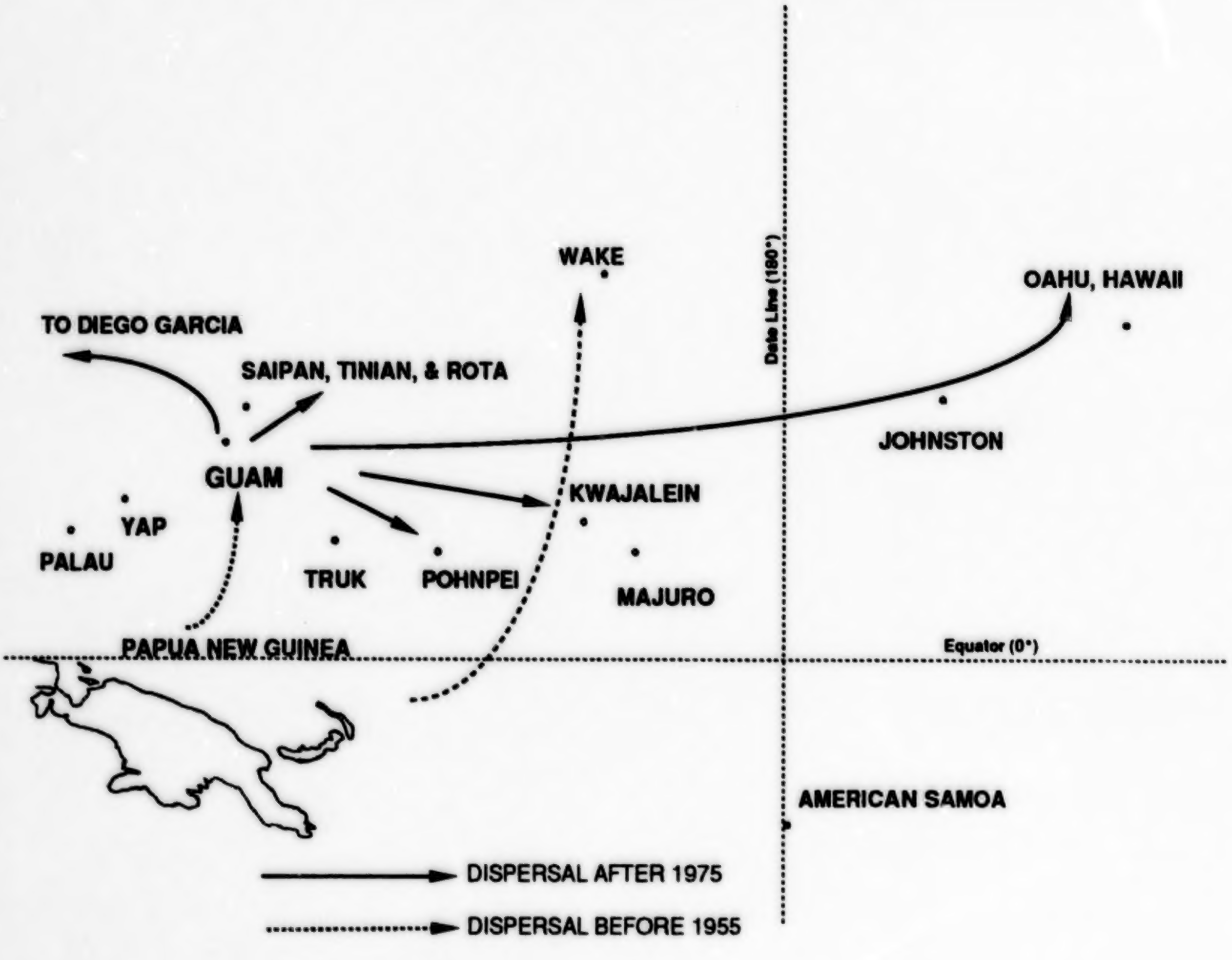
The Brown Tree Snake, *Boiga irregularis*, A Threat to Pacific Islands



Fish and Wildlife Service

U.S. Department of the Interior

Biological Report 88(31)
September 1988

The Brown Tree Snake, *Boiga irregularis*, A Threat to Pacific Islands

by

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Preface

The brown tree snake poses a threat to the ecology, economy, and general quality of life on Guam and is likely to cause similar problems on a variety of other islands in the Pacific region if the snake becomes established through intentional introductions or passive dispersal. The most likely mode of future dispersal will be snakes arriving to new islands as stowaways in cargo. Numerous examples document this snake in military and civilian cargo and aptly illustrate the importance of a program to reduce these incidents. The task of preventing snakes from being carried from Guam to other Pacific Islands is a complex one involving several elements and diverse governmental agencies and private companies. The success of efforts to minimize the dispersal of snakes will involve active programs on Guam as well as on the islands judged most likely to receive the snake.

Acknowledgments

Many people have contributed ideas, comments, and data to this review of the brown tree snake problem. The patience and support of Patricia Fritts and Rayann Robino allowed me to work on this manuscript for so long and contributed substantially to the final product. John Engbring, Ernest Kosaka, Gordon Rodda, Rayann Robino, and Brian Smith made suggestions that improved the organization, content, and readability of the manuscript. Carolyn Imamura, Phil DeLongchamps, and especially Ernest Kosaka encouraged the work which led to this report.

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Fieldwork on Guam has been supported in part by the Department of Interior Technical Assistance Program, Guam Power Authority, U.S. Navy, U.S. Air Force, as well as offices of the U.S. Fish and Wildlife Service in Honolulu, Hawaii; Portland, Oregon; and Washington, DC.

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The Brown Tree Snake, *Boiga irregularis*, A Threat to Pacific Islands

Introduction

Today, much of the native bird fauna of Guam is extirpated from the island, and with few exceptions the native and introduced species that remain are on the verge of disappearing (Marshall 1985; Savidge 1987; Engbring and Fritts, in press). These island-wide extinctions are primarily due to a single factor (Savidge 1987): the introduction of an exotic snake, the brown tree snake (*Boiga irregularis*). Like most Pacific Islands, Guam completely lacked snakes (except for a harmless and inconspicuous burrowing species that few people would recognize as a snake) until the introduction of the brown tree snake. The birds of Guam evolved in the absence of snake predators. Since the birds of Guam had no experience with such a predator, they apparently lacked protective behaviors against the brown tree snake, and were easy prey for these efficient, nocturnal predators. Once the invasion had taken hold, the snakes spread across the island, the number of snakes began to grow exponentially, and bird populations began to decline (Savidge 1986). As the snake population grew, snakes began causing interruptions to electrical supplies and damage to electrical equipment when they caused electrical shorts and major power failures by climbing on high voltage lines. This frequent problem hampers nearly every facet of civilian and military activities on Guam and constitutes a severe economic burden of millions of dollars in damages to equipment and loss of work productivity for the island (Coulehan 1987; Teodosio 1987).

The snakes also constitute a significant agricultural pest around poultry, domesticated birds, other farm animals, and pets. Numerous reports exist of snakes killing and devouring chickens, pigeons, caged song birds, and bird eggs. Hungry snakes occasionally attack and kill newborn pigs and dogs, even when the intended prey is too large to be swallowed. Nearly everyone on Guam who has attempted to raise chickens or other domesticated birds has had snakes invade roosts and cages in search of prey. The loss of insectivorous birds and changes in the abundance of insectivorous lizards have likely led to an increase in insect abundance and made the invasion of insect pests from other islands and from outside Micronesia much more likely. This vulnerability to insect colonization either by natural dispersal or by insects arriving by surface or air transport may lead to insect damage to agricultural crops and natural vegetation by herbivorous insects and increased health problems for humans and domesticated animals due to diseases carried by insects.

Clearly the total scope of the damages and effects of the brown tree snake invasion of Guam has not been defined. However the data available are sufficient to conclude that this snake is a significant pest capable of producing ecological, technical, and economic problems on Pacific Islands.

The danger now exists that the brown tree snake will be transported to other Pacific Islands where similar "naive" bird communities will be equally vulnerable to extinction and where similar technical and economic problems could develop as a result of uncontrolled snake populations. The purpose of this report is to summarize the biological information available on the brown tree snake; to inform wildlife, agriculture, customs, and other responsible agencies in Pacific Island governments of the danger that exists; and to outline steps necessary to prevent dispersal and establishment of introduced snake populations on Pacific Islands.

The Brown Tree Snake in Its Native Range

Distribution

The brown tree snake is a member of the Family Colubridae and is native to coastal Australia, Papua New Guinea, and a large number of islands in northwestern Melanesia. The species occurs on both large and small islands (Figure 1), extending from Sulawesi in eastern Indonesia (near Wallace's Line) through Papua New Guinea and the Solomon Islands and into the wettest coastal areas of Northern Australia (Kinghorn 1964; McCoy 1980; In Den Bosch 1985). Individuals of this species have been discovered on several extralimital islands, but the snakes on Guam represent the only established population outside the native range (Fritts 1987a).

Diet

The brown tree snake is known to feed on a broad variety of prey species in its native range. Prey in Australia and the Solomon Islands consists of lizards, small mammals, birds, and birds' eggs (Worrell 1963; Cogger 1975; McCoy 1980). The brown tree snake is commonly found in bird and poultry cages which it enters at night and, after swallowing birds or eggs, is unable to leave because of prominent lumps in the otherwise slender body (Worrell 1963; Cogger 1975). In Papua New Guinea the brown tree snake regularly takes eggs and chicks, but rats and mice are the preferred food (Parker 1983). Preliminary data on food items found in museum specimens collected throughout the native range suggest that birds form a more conspicuous part of the diet on small islands but that mammals are much more important in the diet on the Island of Papua New Guinea (Greene, in prep.). Frogs (McCoy 1980; Parker 1983) and other snakes (Fritts and Scott 1985) are also occasionally eaten. Apparently, the small snakes depend primarily on lizards, small birds, and eggs of lizards and birds, whereas larger individuals feed to a greater extent on adult birds, mammals, and larger prey items (Savidge 1986; Greene, in prep.).

Reproduction

The reproductive characteristics of the brown tree snake are poorly known. The female of this species produces 4-12 oblong eggs (Zwinenberg 1978). The eggs are 42-47 mm long and 18-22 mm wide (Parker 1983). They are covered with a leathery shell and often adhere together after the egg shell dries. Eggs are abandoned by the female in hollow logs, rock crevices, and sites where they are protected from drying and high temperatures. Females are capable of producing two clutches per year but the timing of reproduction may depend on seasonal variation in climate and prey abundance. Like females of other snake species, the female brown tree snake may be able to store sperm and produce eggs over several years after a single mating.

Habitat Use

Despite its common name, the brown tree snake is not restricted to forested habitats. In Papua New Guinea it occupies a wide variety of habitats at elevations up to 1,200 m (Parker 1983). It is most commonly found in trees, caves, and near limestone cliffs but frequently comes down to the ground to forage at night (Cogger 1975; McCoy 1980). It hides during the day in the crowns of palms, hollow logs, rock crevices, caves, and even the dark corners of buildings near the roof (Cogger 1975; McCoy 1980; Parker 1983). Based on frequent mention of this snake in relation to buildings, domestic poultry, and caged birds, the snake is probably common in human-disturbed habitats and second-growth forests.

Abundance

The brown tree snake is reportedly fairly common in New South Wales (Kinghorn 1964) and is likely to be locally common everywhere else where it occurs in Australia. It is one of the most common snakes in the Central Province of Papua New Guinea and perhaps through most of lowland New Guinea (Parker 1983). Curiously, the species is reported to be uncommon in the Solomon Islands (McCoy 1980).

Size

The maximum length of snakes in Australia and the Solomon Islands is about 2 m

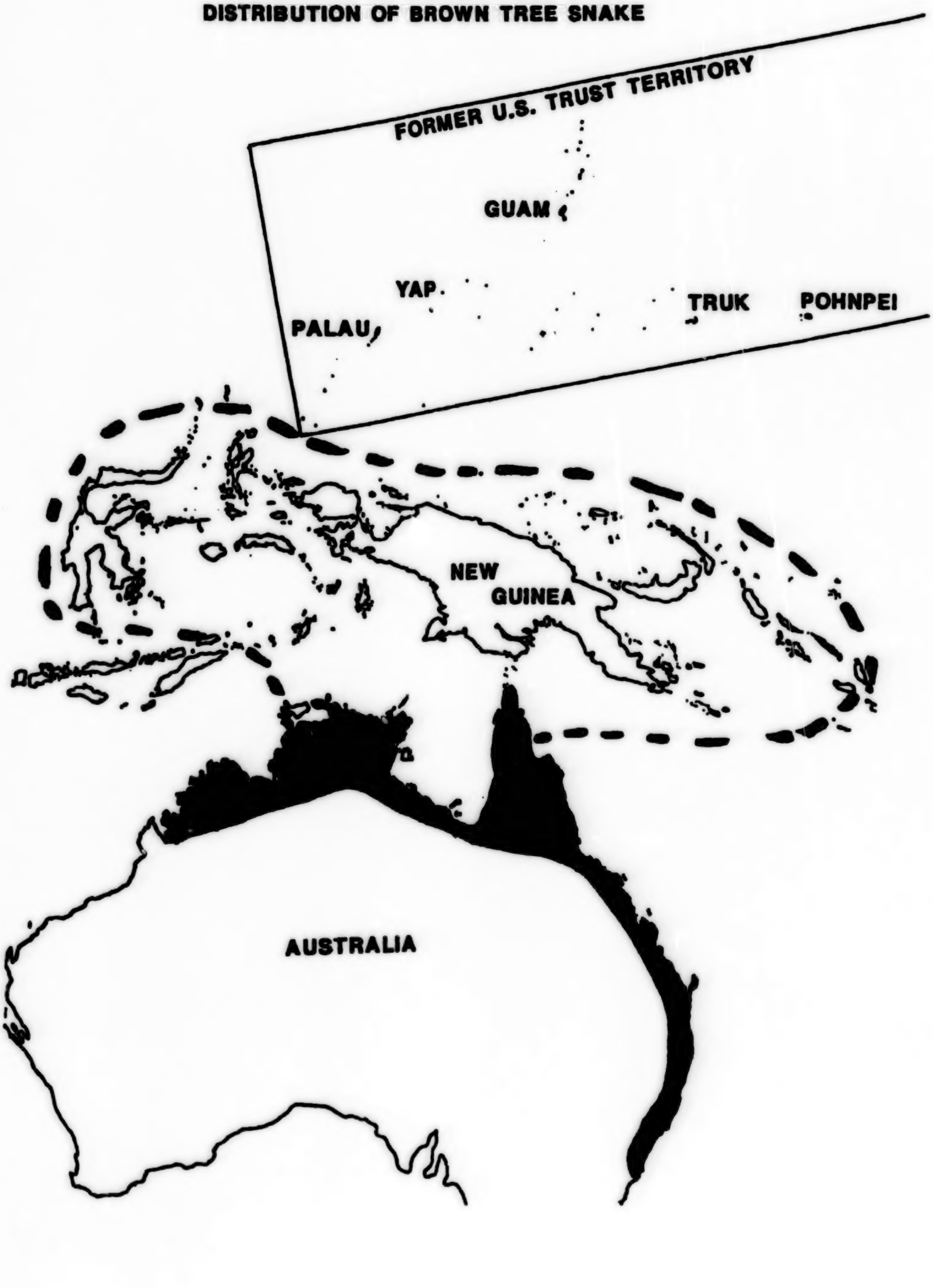


Figure 1. The distribution of the brown tree snake, *Boiga irregularis*, (hatched and shaded areas) in relation to Guam and the former U.S. Trust Territory Pacific Islands.

(Kinghorn 1964; Cogger 1975; McCoy 1980), but in New Guinea the species grows to over 2.3 m, with most large individuals around 2 m (Parker 1983).

Defensive Behavior and Toxicity

When threatened, the brown tree snake is extremely aggressive (Figure 2) and likely to lunge and bite repeatedly (Worrell 1963; Johnson 1975; McCoy 1980). Defensive behavior is often accompanied by lateral compression and inflation of the neck region and a pronounced exaggeration of the head width relative to the neck. Head hiding and tail lashing are other defensive behaviors commonly seen in this species (pers. obs.) although neither of these actions was reported by Johnson (1975).

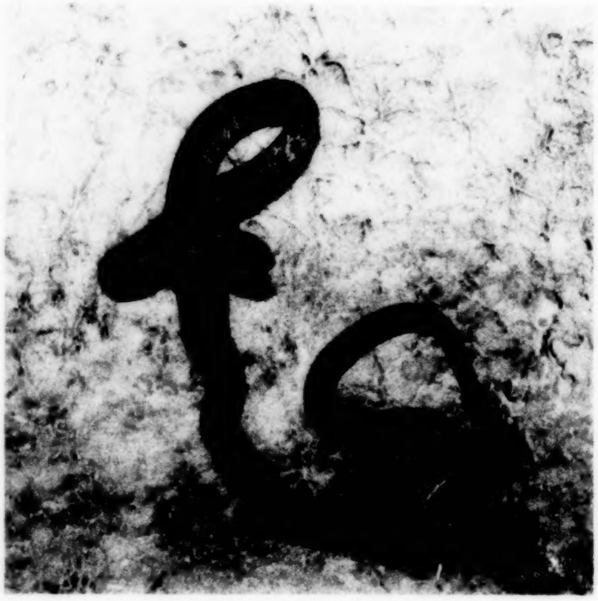


Figure 2. The brown tree snake, ***Boiga irregularis***, in the defensive posture from which it will lunge and attempt to bite.

The bite frequently results in bleeding where the teeth break the human skin (Worrell 1963). This snake is commonly reported to be harmless by Australian authors who are familiar with a variety of deadly elapids (Cogger 1975), but the brown tree snake is equipped with an enlarged venom gland, recurved and grooved fangs located at the rear of the mouth (Figure 3), and a disposition causing it to attempt to bite whenever it is molested (Parker 1983). According to Parker the bite causes local swelling and itching, and feels comparable to a bee sting. The venom of two related species (Genus *Boiga*) has been shown to cause medically important reactions to humans (Burger 1974; Levinson et al. 1976). Some medical risk exists to infants, elderly people, and anyone with extreme allergic reactions suffering serious bites by this snake, especially if the snake is allowed to chew or hold on after the initial strike.

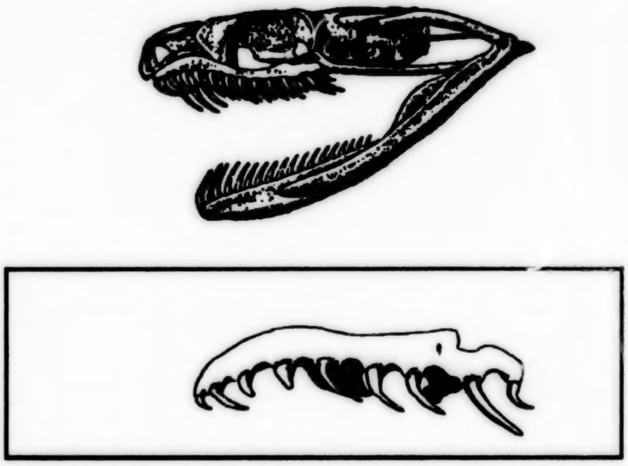


Figure 3. The brown tree snake has numerous teeth but only the last two teeth on each side of the upper jaw (box) have grooves which inject venom when the snake bites during feeding or defense.

Even though it has a large venom gland, this snake is not usually effective in injecting the venom when biting humans because the recurved fangs that inject the venom are located in the rear of the mouth. Thus the mouth must be opened as wide as possible and a deliberate chewing movement must be employed to inject the venom by means of capillary action along the grooved fang. The venom is used to subdue and kill the birds, mammals, and lizards on which this snake normally feeds. The snake often wraps its body around the prey to immobilize it while chewing on the animal to inject the venom with the teeth located in the back of the mouth.

The Brown Tree Snake in Guam

Introduction of Snakes to Guam

Prior to the arrival of the brown tree snake to Guam, the only snake present on the island was a blind snake, *Rhamphotyphlops braminus*. This secretive wormlike snake inhabits termite nests and loose soil where it feeds on termites and ants. Its small size and lack of well-developed eyes contribute to most island residents failing to recognize it as a snake rather than a worm. As a predator of arthropods, the blind snake poses no threat to Guam's fauna or human population. Thus, Guam effectively lacked a conspicuous snake until the brown tree snake became established.

How the brown tree snake arrived to Guam is unknown, but the snakes probably arrived as passive stowaways in military cargo from the Papua New Guinea area in post-war years (Fritts and Scott 1985). Like many Pacific Islands, Guam has historically had high populations of introduced rat species, and some people in Guam claim to know that the U.S. military intentionally introduced the snakes as a biological control agent for rats. Although an intentional introduction cannot be ruled out, no written documentation exists of such an introduction as an attempt to control rats. The brown tree snake is known to hide in artificial daytime retreats such as maritime cargo and aircraft, and therefore this species is likely to be moved around by man as a passive stowaway (Fritts 1987a) and could be introduced unwittingly.

Brown tree snakes were common on several islands on which important battles and military facilities were located during the World War II period (e.g., Guadalcanal and Manus), and these snakes were conspicuous to the combat and support troops visiting the Papua New Guinea and Solomon Island areas (Pendleton 1947). A brown tree snake recorded near a military runway on Wake Island in 1946 was assumed to have arrived in military cargo (Bryan 1959). This specimen may have been mislabeled in the Bishop Museum in Honolulu, Hawaii; a specimen with these data is recorded in the collections, but no voucher specimen is available to substantiate the occurrence.

On the basis of variation in scalation patterns, the snakes on Guam are most similar to those of the Admiralty Island group of northern Papua New Guinea (Fritts, in prep.). This is possibly the area from which the snakes on Guam were introduced.

Distribution

The brown tree snake was first detected in the 1950's on Guam in the Santa Rita area near the Naval Port (Savidge 1986), but snakes may not have become conspicuous until the early 1960's (B. Duncan, pers. comm.). By the mid 1960's the snake had colonized over half of the island's area (Savidge 1986). In 1968, the snake had reached the extreme northern end of the island (Savidge 1987) and was probably present throughout the island.

Diet

A considerable body of knowledge indicates that the brown tree snake is directly responsible for major declines within bird, mammal, and lizard populations on Guam and for the local extinction of several species. The feeding habits of brown tree snakes on Guam are just as broad as in its native range, but with the vulnerable bird species already eliminated, it is now difficult to quantify their dietary preferences. Furthermore, young snakes now have little opportunity to learn about birds as prey. Whether birds are a preferred food item on Guam, or just more vulnerable to being wiped out by snake predation is not clear. Snakes on Guam are attracted to bird odors (Fritts et al., in press) and to live, caged birds placed in the field (Savidge 1987). Because the major portion of the native bird fauna has disappeared, most birds and bird eggs found in snakes from Guam are domestic poultry, caged birds, and other domesticated or introduced species (Savidge 1986).

In areas away from human habitation on Guam, where birds are rare or nonexistent, brown tree snakes eat a variety of lizards (Smith and Fritts, in prep.). Some lizards may have disappeared or become scarce on Guam due to intense predation by the brown tree snake, but data on lizard abundance prior to the establishment of the snake are inadequate to measure such faunal changes (Fritts, in prep.).

The generalist feeding habits of the brown tree snake on Guam cause serious problems since snakes can easily switch prey types and maintain high population levels even after preferred food items are precariously low in abundance. Thus, high snake population density is maintained even as some prey species decline and disappear, and the snakes continue to take endangered birds as they are encountered, until the most vulnerable bird species are extinct. The abundance of lizards as a prey base for young and subadult snakes will insure the survival of the snake population even if bird and mammal populations continue to plummet. Whether these small prey items are appropriate for the large adults is not clear, but a tendency to find large snakes in urban areas and near agricultural settlements where poultry and rats are relatively more abundant, suggests that growth, if not survival, of adults may hinge upon the availability of prey larger than most lizards (geckos and skinks). Numerous reports exist in Guam of brown tree snakes killing and attempting to eat prey which would normally be considered too large to eat. Snakes in Guam are known to have killed newborn German shepherd puppies, piglets, domesticated pigeons, and caged rabbits.

Reproduction

Few data are available on the reproduction of the snake in Guam. Young snakes with umbilical scars indicating that they had hatched within the last few months were common in June and July collections made by Fritts and Scott (1985). Snakes with enlarged follicles or shelled eggs have been collected in several months of the year suggesting a long reproductive season and the possibility that a female can lay more than one clutch per year (Guam Division of Aquatic and Wildlife Resources, unpubl. data). A female snake approximately 1.5 m in length deposited four eggs in November of 1987 after several months in captivity, but none of the eggs developed.

Habitat Use

The brown tree snake, like most arboreal snakes, is an exceptional climber (Figure 4). The body is long and slender, which facilitates vertical and horizontal reaches from one limb to another across large gaps in the forest canopy. The long tail is frequently knotted around any projection available when the snake is in danger of slipping or falling (Fritts 1987b). The long, slender body not only helps the snake to move from tree to tree in search of prey, but also enables it to get through tiny spaces or up into the rafters of houses or warehouses, where a snake may stay for a long time without being detected.

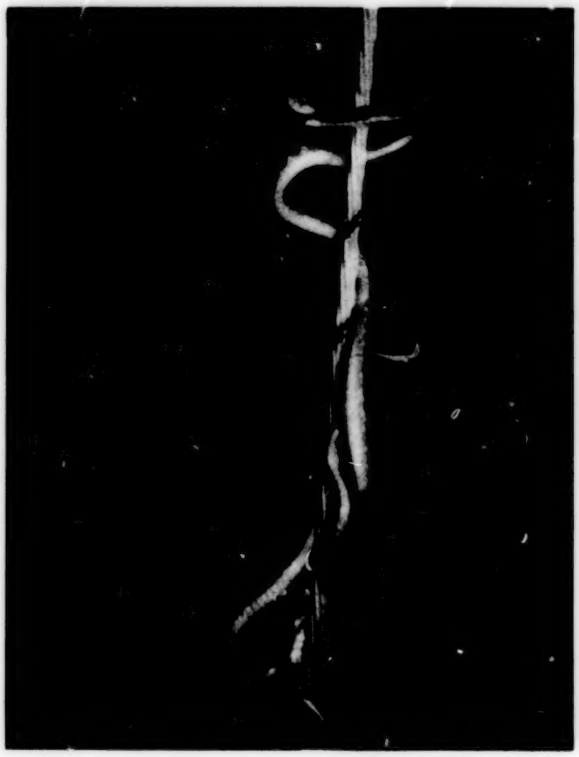


Figure 4. A brown tree snake clinging to a vertical cable used as a guy wire on an electrical pole in Guam.

The brown tree snake is a nocturnal snake that can easily escape notice except under unusual conditions. During the day, it seeks seclusion from heat and bright light. Normally it finds hiding places in hollow trees, crowns of palms, rocky cliffs, caves, and other natural features that provide dense shade and moderate temperatures. However, when it occurs in areas close to human settlements, hiding places can be drain pipes, rafters of buildings, vehicles, and a host of other man-made objects.

On Guam, residents have reported finding snakes in nearly every conceivable situation (Figure 5). Snakes have been found in light fixtures, toilets, cabinets, stairwells, and beds. Snakes are most commonly found in bathrooms, which they enter through the sewer lines connecting to toilets and other fixtures. Apparently, snakes commonly crawl onto roofs from nearby trees and utility wires and gain access to sewer pipes by crawling down vent pipes that open onto the roof. Once inside the sewer vent, the snake may take the lateral exit, force its way the short distance through the water standing in the trap or toilet bowl and enter the building. The habit of seeking refuge in daylight hours apparently accounts for most instances of snakes entering homes and other human environments.

Many people in Guam believe that the snakes are attracted to lemon trees. Whether lemon trees are indeed attractive to snakes because of lizards or other potential prey that inhabit them or, alternatively, because snakes seeking shade in the daytime are more likely to be discovered in lemon trees when people are picking fruit is unclear. Many snakes are also discovered in the vicinity of human residences when vegetation is being trimmed or cleared during daylight hours.

It may be exceedingly difficult to locate snakes in man-made structures since they can crawl into surprisingly small areas. Even exhaustive visual searches may not be adequate to locate snakes known to be in the vicinity unless they are actively moving.

Figure 5. A collection of 16 snakes taken from a single span of cyclone fencing near the Guam International Airport in one evening.

Abundance

The brown tree snake is exceptionally abundant on Guam. More snakes can be caught per hour by an experienced snake collector in Guam where only the brown tree snake and blind snake occur (Fritts and Scott 1985) than in the rainforests of the Amazon Basin of Ecuador where 51 snake species occur in sympatry (Duellman 1978). Night collecting for snakes in Guam may be as much as eight times more effective than in the Amazon where the native snake fauna is so diverse, but where population levels are controlled by complex ecological processes. Snakes are found throughout Guam, but based on timed constraint collections, the densest populations in forested areas near clifflines were estimated to be up to four times as dense as the more sparsely occupied forest areas (Fritts and Scott 1985).

Trapping studies have also documented a dense snake population on Guam. An intensive trapping effort in a 1-hectare plot resulted in the capture of 50 snakes during a 47-day period (Fritts et al., in press) Although all 50 individuals may not have been present in the area when the trapping was begun, the snakes represent the number of potential predators on any birds resident within the area during the period. Using 50 snakes per hectare and assuming similar densities in adjacent forest, a density of 5,000 snakes per kilometer^2 (or nearly 13,000 per mile^2) would be estimated. Based on comparisons of trap success in peripheral versus interior traps, Savidge (1986) estimated a density of 16 snakes per hectare for one site (1,600 per kilometer^2 or 4,144 per mile^2).

The density of the snake population in Guam is a key factor contributing to the ability of the brown tree snake to cause the extirpation of the bird fauna of the island and the variety of other problems caused by the snake. Traps placed on the guy wires of two electrical poles caught seven snakes in a period of 14 days (Fritts and Scott 1985). The dense snake populations in concert with the vulnerability of the native birds and the broad feeding habits of the snake contributed to the inevitable crash of the bird populations of Guam.

Predation rates measured by Savidge using domestic quail held in snake traps scattered in the forest demonstrated that snake densities and movements were sufficient to result in 75% predation in 4-11 nights at sites where snakes were judged to be dense and 25%-45% predation in 14 nights at two forested sites where densities were judged to be lower.

Size

On Guam, snakes can attain a total length exceeding 2.4 m and can therefore feed on a wide range of prey (Fritts and Scott 1985). Snakes 2-2.4 m in length can weigh about 2 kg. Brown tree snakes may be somewhat smaller in Australia and the Solomon Islands where maximal sizes are reported to be around or only slightly larger than 2 m (McCoy 1980; Cogger 1983). Except for individuals larger than 2 m, they are relatively slender. However, they have an extremely wide mouth gape and the ability to distend their bodies to accommodate large prey.

About 51% of the brown tree snakes encountered in forested areas are juveniles or subadults measuring less than 80.1 cm in body length (Figure 6). This is a higher percentage of young snakes than is evident in samples of the species from its native range. Only 27% of all snakes encountered in Guam have a body length exceeding 1.07 m, and only 2% exceed 1.8 m. This suggests that reproductive rate and juvenile survivorship are high, despite the decline in birds and rodents typically exploited as prey by adult snakes.

Potential Predators on Guam

Few animals on Guam prey on the brown tree snake, and most of those that do are introduced species with patchy distributions on the island. Feral pigs and cats may occasionally prey on brown tree snakes (Fritts 1984), but neither species is sufficiently abundant or uniformly distributed on Guam to exert a significant control on snake populations throughout the island. In addition, neither species is a desirable control agent for snakes, because both pigs and cats are known to have produced severe ecological damage when present at high densities on islands (Thornton 1971). The monitor lizard (*Varanus indicus*), which probably arrived on Guam with the Chamorros and may have been there for as many as 1,000 years, is also known to kill and eat the brown tree snake (T. Fritts and G. Wiles, pers. obs.). The impact that predation by monitors could have on snake populations is not known, but monitors could be important in reducing the likelihood of snakes becoming established on islands when snake populations are low and most individuals are small. However, young monitor lizards may be as vulnerable to snake predation as the snakes are to predation by adult lizards, and at least initially, the advantage would rest with the most abundant of the two predators. Monitors were undoubtedly much more common on Guam in the 1960's when the collections studied by Dryden and Taylor

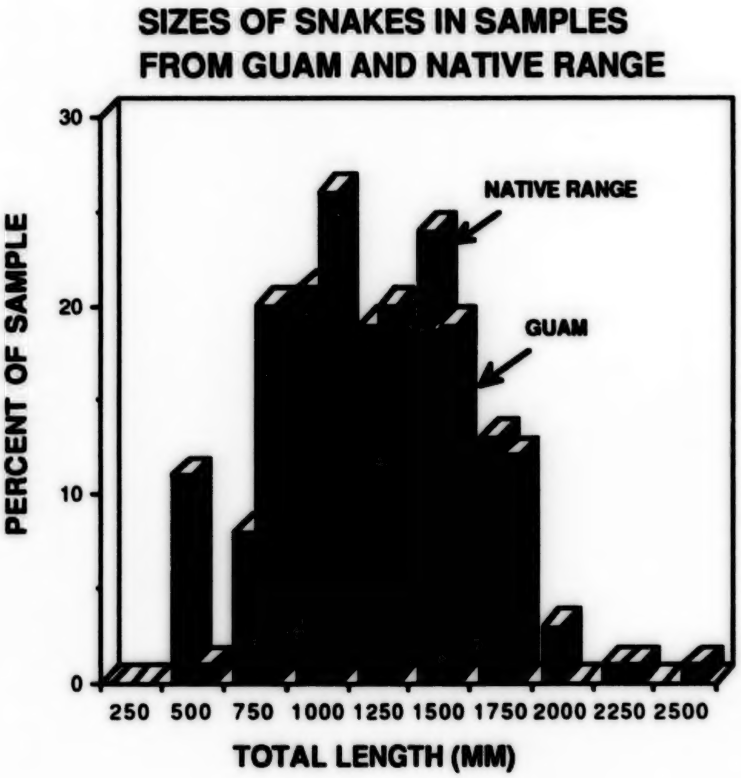


Figure 6. Variation in size of snakes caught in forested habitats on Guam in 1985 showing the predominance of small individuals and subadults less than 1 m long relative to samples from the native range.

(1969) were made. The decline of monitors may be in part due to the tendency of the lizards to rest on roads where they are vulnerable to automobile traffic.

Factors Influencing Snake Dispersal

The chronology of the disappearance of birds from the central and southern parts of Guam before the northern region, and the relatively similar pattern of when snakes became conspicuous to island residents in various regions of the island described by Savidge (1987), may be more reflective of when snake populations soared to extremely high levels than of the first dispersal and colonization of the individual region or habitat by snakes. Snakes were known from Ritidian Point (the extreme northern point on the island) as early as 1968 (R. Crombie, pers. comm.), but were judged to have expanded into this region 12 to 15 years later by Savidge (1987), based on interviews with island residents and the detectable declines in forest bird species. Thus snakes were present in northern Guam for up to 15 years before they became obvious and before the impact on the bird fauna was detected.

Most of the northern part of Guam is under the control of Andersen Air Force Base and adjacent naval facilities. The presence of these military facilities has resulted in the preservation of some of the most natural limestone forests and in the buildup of dense pig populations due to restricted hunting. Consequently, pig populations on some parts of the base far exceed those anywhere else on the island, and the same may be true for monitor lizards, which are most abundant on the base. The possibility exists that the abundance of pigs and monitors impeded the otherwise exponential population expansion of snakes on northern Guam.

In addition, the existence of taller, more complex native forest, instead of disturbed second-growth forests provided better survivorship for native forest bird species. Elsewhere on Guam, snakes had few predators and the bird fauna was potentially more vulnerable in the simple second-growth forest habitats, whereas potentially in the north, snakes had lower survivorship and birds had increased protection from predation possibly because of the taller, more diverse limestone forest there.

The role of predation on snakes by pigs and monitor lizards remains unclear, but sufficient evidence exists to prompt further study of these animals as control agents. Although the monitor is widely regarded in the Marianas Islands as a pest around poultry and is known to occasionally consume the eggs and nestlings of native birds (Dryden 1965), the benefits of predation on snakes may offset these otherwise negative habits.

Other Sources of Mortality

Highway traffic kills snakes that are forced to cross busy thoroughfares when moving from one forest patch to another, but relative to the total snake population on Guam such highway mortalities are inconsequential. The combination of small habitat patches and heavy automobile traffic may keep snake abundance low in some urban areas. The presence of dead snakes on roads, however, may be the first and most conspicuous indication of a newly established population on any island not already known to have native or introduced species of snakes.

Ecological, Technical, and Economic Problems

Brown tree snakes have caused major problems directly impacting the ecology and human population of Guam. The best documented of these are the loss of the native bird fauna and the frequent power outages caused by snakes. Other effects include predation on agricultural animals and pets, increased vulnerability of agricultural crops and native vegetation to insect pests, increased risk of insect-borne diseases affecting humans and other animals, and the fear or repulsion experienced by most residents and visitors to Guam when they encounter snakes in natural and urban settings. Several of these problems are less easily quantified than others. The cumulative negative impacts of the brown tree snake on commerce, the tourist industry, the military, and the civilian population of Guam have not been estimated, but are likely to be significant (Coulehan 1987).

Impacts on the Birds of Guam

By 1963, several formerly abundant species of native birds had disappeared from the central part of the island where snakes were most populous. By the late 1960's, birds had begun to decline in the central and southern parts of the island and remained abundant only in isolated patches of forest on the northern end of the island (Jenkins 1983). Snakes began affecting the birds in the north-central and extreme northern parts of the island in the 1970's (Jenkins 1983; Engbring and Ramsey 1984; Savidge 1986) and most native forest species were virtually extinct when they were listed as threatened or endangered by the U.S. Fish and Wildlife Service in 1984 (Engbring 1985; Marshall 1985).

At present even small mammals are extremely rare in most forested habitats of Guam (Savidge 1987; pers. obs.). Predation by the brown tree snake may be the primary factor preventing recruitment to the single population of native Mariana fruit bat (*Pteropus mariannus*) remaining on Guam. Despite protection from illegal hunting and human disturbance, the bat population has not expanded in recent years (Wiles 1987).

Because the brown tree snake was able to shift from birds to rodents or lizards, snakes apparently were able to subsist on mammals and lizards and continued to take birds when encountered even after the birds were virtually extinct. The birds remaining on Guam after 1984 were extremely patchy in distribution, occurring only in special habitats where some protection existed from snakes. By 1986, nine species of native forest birds were extinct due to snake predation and several other native birds not limited to forests were severely affected by snake predation. Four other species, including three seabirds, are absent or extremely scarce.

While the snake is present, it would be futile to restock the extirpated bird species on Guam from captive stock or populations on other islands. Even though abundant forest habitat exists for birds on Guam, it remains unsuitable for birds due to the high predation by the brown tree snake.

The birds remaining on Guam in 1987 are either introduced birds with some defense against snake predators (Black Drongos, *Dicrurus macrocercus*, and Black Francolins, *Francolinus francolinus*) or are among the largest of the native birds (Mariana Crow, *Corvus kubaryi*). Two species (Yellow Bittern, *Ixobrychus sinensis*, and Pacific Reef Heron, *Egretta sacra*) may be best equipped to defend themselves with their long bills and fighting manner.

Most of the birds remaining on Guam are probably partially protected by having some antipredator defense behaviors, by occurring in habitats where the snake is least successful, or by simply being too large as adults for all but the largest brown tree snakes to eat. Examples are the Philippine Turtle Dove (*Streptopelia bitorquata*), Black Drongo, Red Jungle Fowl (*Gallus gallus*), and Black Francolin, all of which are introduced species originating from areas with native snakes.

The turtle dove has been shown to have extremely high nest predation even in areas where snakes may be less abundant than in most forested habitats (Conry 1987). The high reproductive rate, ubiquitous habitat tolerances, and defensive behavior of the turtle doves have probably contributed to their survival in Guam.

The drongo is an extremely aggressive defender of its nests. It perches and nests most commonly on the tops of objects such as trees or power poles. Nests are found near the tops of trees in native forest on Guam, but most nests known to successfully produce young are found on power poles, which are more difficult for the snakes to climb than trees. The numbers of adults, young in nests, and empty drongo nests on power lines traversing the Northwest Field of Andersen Air Force Base declined precipitously between June 1985 and August 1987 (Fritts, unpubl. data), and this decline appears to be caused by snake predation. Drongos are much more common on Rota, which lacks snakes, than on Guam, where the snake is present.

The francolin is a large bird that produces large numbers of young each year and frequents the grassland areas least used by the arboreal brown tree snake. The francolin is native to India, which has a diverse snake fauna.

The Eurasian Tree-Sparrow (*Passer montanus saturatus)* may have persisted only because it is so successful in urban areas surrounded by automobile traffic, domesticated animals, and habitat discontinuities, all of which potentially reduce the abundance of the brown tree snake.

Snakes undoubtedly take all of these species, but to date these introduced birds have not been reduced to the precariously low population levels that the native species have reached.

One of the last native birds to disappear, the Guam Rail (*Rallus owstoni*), and one of the native forest bird species remaining on Guam, the Mariana Crow, are relatively large and, like the Yellow Bittern and Pacific Reef Heron, may be able to defend themselves somewhat with their bills.

Reef Herons, Yellow Bitterns, Micronesian Starlings (*Aplonis opaca guami*), Brown Noddys (*Anous stolidus*), White Terns (*Gygis alba*), and Philippine Turtle Doves are all conspicuous on the small island of Cocos, to which snakes have not yet arrived. These birds are relatively infrequent on Guam, where they are in contact with snake populations.

The birds that declined first in the face of snake predation were those with small body sizes allowing most snakes to feed on eggs, nestlings, and adults whenever they were encountered (Savidge 1986). Examples of the small birds that once were abundant on Guam and are now extinct (Savidge 1987) include: the Guam Flycatcher (*Myiagra freycineti*), the Rufous Fantail (*Rhipidura rufifrons uraniae*), the Bridled White-Eye (*Zosterops conspicillatus*), and the Micronesian Honeyeater (*Myzomela rubrata saffordi*). The Island Swiftlet (*Aerodramus vanikorensis bartschi*) is a small bird which is also reduced in numbers but it may be protected in part by its exclusive use of the ceilings and vertical walls of caves for roosting and nesting.

Two doves somewhat larger than the smallest birds have also declined on Guam. The White-throated Ground-Dove (*Gallicolumba xanthonura*) is virtually extinct on Guam, and the Mariana Fruit-Dove (*Ptilinopus roseicapilla*) has not been observed on the island since 1984.

Two other birds intermediate in size and preferring to nest in cavities more protected from snakes are the Micronesian Starling and the Micronesian Kingfisher (*Halcyon cinnamomina cinnamomina*). The starling persists only in the most developed areas of Andersen Air Force Base and in other special situations on Guam. The few kingfishers still left are found in isolated patches of secondary forest on Andersen Air Force Base. These individuals may persist because the nests that are known are in somewhat isolated forest patches surrounded by labyrinthine service roads and are in cavities in trees partially isolated from the canopy of the surrounding trees. The Micronesian Kingfisher frequently preys on skinks and geckos, and possibly even preys on small snakes when they are encountered. The kookaburra or laughing jackass (*Dacelo novaeguineae*) of Australia, a relative of the kingfishers, is known to be a snake predator (Engelmann and Obst 1982).

Electrical Problems

These arboreal snakes are commonly encountered climbing on man-made structures. Snakes climb guy wires leading to power poles supporting transformers, distribution lines, and high-voltage transmission lines (Fritts 1987b; Fritts et al. 1987). When the snakes simultaneously touch live and grounded conductors, they create short circuits and cause electrical faults. This has resulted in frequent losses of power to parts of the island, and has even caused islandwide blackouts (Anonymous 1986). Such power failures, brownouts, and electrical surges in turn damage electrical appliances and interrupt all activities dependent on electrical power. Power outages caused by snakes have been a serious problem on Guam for several years, and the incidence of snake-caused outages increased fivefold from 1978 to 1982, a period of rapid snake population growth (Fritts et al. 1987). In 1982, snakes caused a total of 84 major faults accounting for 252 hours of power outages to the electrical system operated by the U.S. Navy. Additional outages occurred on lines maintained by the Guam Power Authority, but a complete record of the outages experienced by the two agencies producing electricity on the island has not been assembled. However, records do show 562 outages caused by snakes in the period of 1978-88. The two agencies are reluctant to provide precise cost figures, but conservatively it can be estimated that power outages on Guam caused by brown tree snakes have cost millions of dollars a year, and the problem has been conspicuous since 1978 (Fritts 1984; Boucheaux 1986; Fritts et al. 1987).

A total of 562 outages have been caused by snakes on Guam from 1978 through the beginning of 1988, with major problems occurring in 1982 and 1985 (Figure 7). One utility pole carrying a 135-kv line has had 17 faults caused by snakes, and additional snakes have been removed from the pole before they caused outages. Since mid-1985, this line has been turned off from dusk to dawn, in effect abandoning it to the snakes during nighttime hours to prevent additional outages. Snakes are so abundant in some areas near power lines that snake traps placed on guy wires

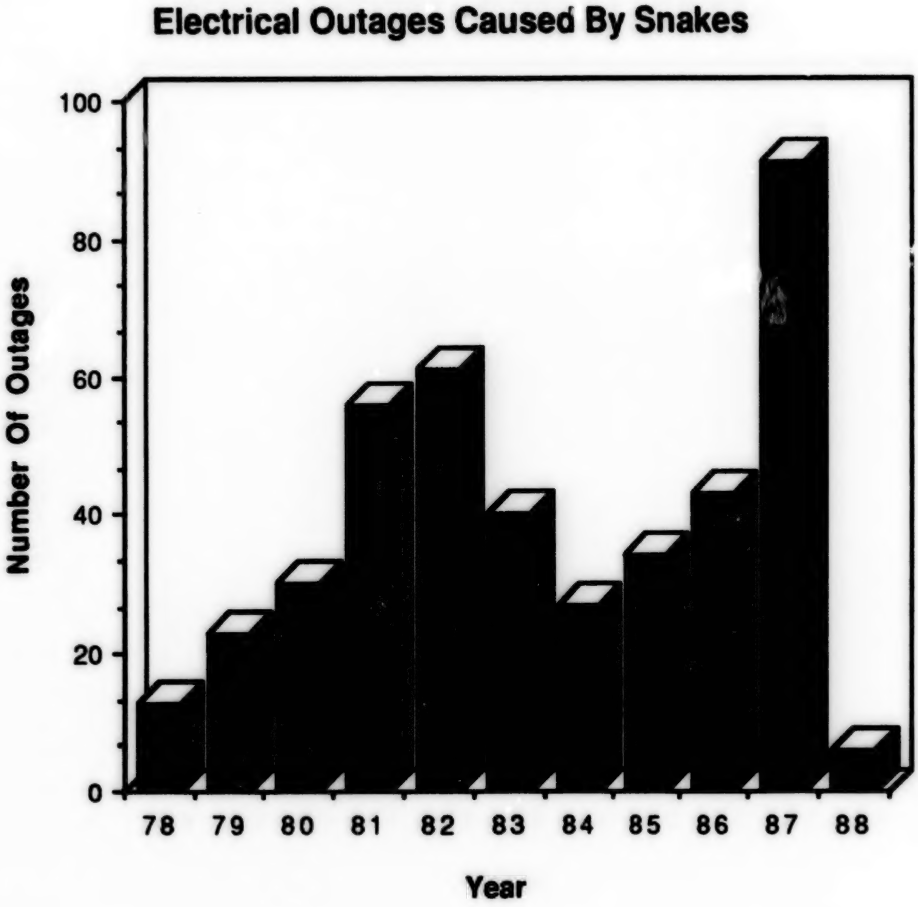


Figure 7. Variation in the number of electrical outages caused by snakes between 1978 and 1988 (part) excluding outages on the x41:x226 circuit which has been deactivated nightly since 1985. The x41:x226 circuit accounted for an additional 138 occurrences of snakes on electrical lines.

captured nearly as many snakes as similar traps placed in forested areas on Andersen Air Force Base (Fritts and Scott 1985).

Guam has 23 major power distribution circuits, and this compartmentalization of the electrical system reduces the chances of outages affecting the entire island or major geographic areas. However, major outages still occur. Many smaller Pacific Islands have far fewer generating facilities and circuits, and once the snake is abundant on these islands the damages to their electrical systems are more likely to affect the entire island or major municipal areas. Many Pacific Islands suffer power supply problems, but the frequency and severity of the snakes on power lines in Guam would be devastating to an island with fewer alternate distribution lines and with less ability to shift to other generating facilities.

An attempt to exclude snakes from one principal transmission line on Guam with large disk barriers on guy wires and stainless steel flashing on poles was partially successful, but the outages continued (Fritts et al. 1987). Snakes gained access to conductors by climbing on guy wires, wooden poles, and adjacent vegetation (Fritts 1987b). Studies presently underway may provide techniques for reducing the number of electrical outages caused by snakes.

The actual cost of electrical outages includes costs passed on to the consumer from the electrical utility and additional costs borne by all electrical consumers in damage to equipment/appliances, spoilage of perishables, and loss of services on which commercial, public, and private consumers depend. Thus the cost of damage to cables, poles, and transformers and the need for emergency repair crews to restore power as quickly as possible is probably only a fraction of the total. Since nearly 95% of all outages caused by snakes occur at night, labor costs are magnified by overtime and the increased manpower needed for night work.

One outage in 1987, which lasted 12 hours and resulted in damage to one of the main generating facilities, was estimated to have cost the Guam Power Authority in excess of $250,000 (Teodosio 1987). Following this incident the Guam Power Authority received 132 monetary claims for domestic appliances and commercial equipment damaged by the brownouts and voltage surges. The exact amount of these claims has yet to be determined. Several large businesses estimated the costs of losing electricity and thus their computerized sales and inventory equipment at $2,000 to $10,000 for one outage lasting several hours (Coulehan 1987).

Snake Bite Risk and Human Fear

This species is technically a mildly venomous snake. On several occasions in Guam, snakes have been found biting and coiled around infants and small children in their beds. A two-month-old boy was treated for respiratory distress about 4 hours after he was discovered in his crib with a snake about 1.5 m (5 ft) in length wrapped around his neck. The snake was biting the boy's arm, but it is unclear whether the respiratory problem originated from effects of the venom or mechanical trauma to the neck of the child (Guam Memorial Hospital records). Of 10 patients of known ages treated at Guam Memorial Hospital for snake bite, five were children less than 3 years of age.

Emergency room records at Guam Memorial Hospital document that 27 snakebite victims were treated in a 14-month period. However, no medically serious bites on adult humans have been recorded, even though about 1 in 1,000 emergency room visits in Guam are for treatment of brown tree snake bites (Guam Public Health data).

Snakes are commonly found in houses and commercial buildings and are a persistent source of irritation and fear to island residents and tourists not accustomed to living with snakes. Many people have a deep-seated fear of snakes, and the vast majority of people resent snakes inside homes, stores, and other human environments. The abundance of snakes in close proximity to people in Guam does have an effect on people's perceptions of the quality of life on the island. Only the U.S. military and government expenditures surpass tourism in economic importance to Guam. Snakes startle tourists, and power outages frequently cut short their enjoyment of Guam's nightlife in restaurants, discotheques, and shopping centers. The invasion of homes by snakes has a definite effect on Guam residents (Guamanians and off-islanders alike), influencing where people live, property values for entire neighborhoods, and decisions about staying on Guam or moving off-island.

Other Damages Related to Brown Tree Snakes

Other long-term damages caused by the brown tree snake in Guam remain to be adequately investigated and defined. The loss of most birds from the island may leave Guam vulnerable to a variety of insect pests. Birds are important predators of insects and, in the absence of bird predation, insects arriving to Guam in ship or air traffic are much more likely to become established and threaten agricultural crops, public health, and the island's ecology. Examples of such problems caused by insect pests include: the outbreak of dengue fever carried by mosquitos, the defoliation of extensive stands of tangen-tangen by an insect arriving from Hawaii, and the host of insects that hamper production of adequate supplies of vegetables by Guam's truck farmers and rural residents.

Changes in the lizard and bird faunas due to snake predation probably have had and will continue to have effects on the abundance of insects on Guam. Lizards, birds, and spiders are major predators on insects. In forested areas of northern Guam where birds have disappeared, snakes primarily prey on lizards. One introduced species, the American anole (*Anolis carolinensis*), is consumed more often than any other lizard species. This lizard was the most common food item found in snakes, but was rarely encountered by biologists working at the site where the snakes were collected (Smith and Fritts, in prep.). It appears that the snakes are proficient at finding and capturing anoles, which sleep at night near the ends of branches in trees. The rarity of the normally conspicuous anoles at the sites suggests that snakes had markedly lowered the lizard population. Conversely, spiders, which are frequently preyed on by lizards and birds, are abundant in the area. The removal of anoles from plots in the Netherlands Antilles resulted in a two to threefold increase in insects on the forest floor and a twenty to thirtyfold increase in large web-building spiders (Pacala and Roughgarden 1984). Similar increases in the abundance and biomass of insects and spiders resulted when lizards were removed from plots in the Bahamas (Schoener and Spiller 1987).

Birds are important in tropical forests because they inadvertently disperse seeds of shrubs and trees and thereby help stabilize forest diversity and recovery after typhoons and other catastrophic events. Whether some trees particularly dependent on bird dispersal of seeds will decline in abundance or disappear is unknown at present.

Threat of Dispersal to Other Islands

Sightings on Other Islands

The brown tree snake has been discovered in several extralimital localities in addition to Guam, but to date Guam has the only reproductive population outside the native range (Fritts 1987a). Discoveries of the brown tree snake have occurred in: Honolulu, Hawaii; Wake Island; Kwajalein Island; and Diego Garcia Atoll (Figure 8). Most of these snakes have been at military airports and in naval cargo.

Snakes, most likely brown tree snakes, have also been sighted on Saipan and Pohnpei. Sightings on Saipan and Pohnpei were associated with commercial ship cargo or not directly attributable to any source. One sighting in Saipan was in close proximity to wooden utility poles recently brought from Guam.

One record exists from the customs area of the Honolulu International Airport on Oahu. A sighting of an unidentified snake on Tinian was reported incidental to bird surveys conducted by Downs (1946). No systematic survey of snake sightings occurring on Pacific Islands has been made and it is likely that other incidents exist of brown tree snakes arriving onto islands outside its native range.

Probability of Dispersal and Colonization

The likelihood of dispersal of snakes from Guam to other Pacific Islands is enhanced by several factors. The central position of Guam in the western Pacific, its importance as a U.S. military center for the Pacific region, and the volume of both civilian and military transportation all contribute to the probability of snakes being carried from Guam to other Pacific Islands.

The brown tree snake's abundance and habits on Guam contribute to the possibility that it will be carried from Guam to other Pacific Islands as a passive stowaway in cargo and baggage. Snakes are abundant near seaports, airports, and cargo facilities. This brings snakes in close proximity to equipment and materials destined for off-island shipment. The habit of seeking out daytime hiding spots protected from heat and light results in the snake entering and remaining within almost any structure offering these conditions, including cargo containers, large equipment, and construction materials stored in transit areas for shipment to other islands.

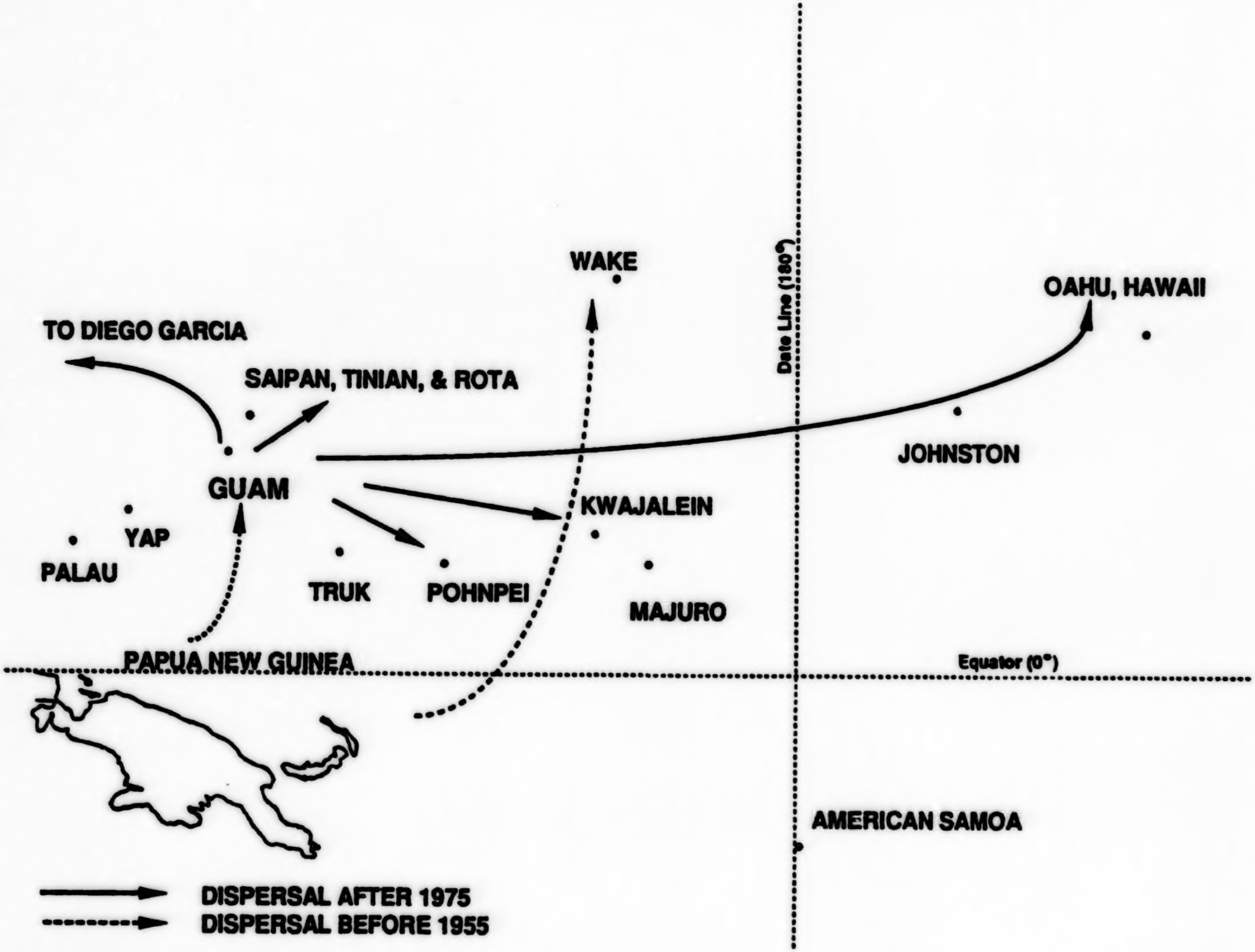


Figure 8. The dispersal of the brown tree snake from its native range in the Papua New Guinea region (dashed arrows) and from Guam (solid arrows). Islands to which the snake is likely to disperse are labeled.

The snake's nocturnal habits may also allow it to escape detection, and residents would be unlikely to realize the presence of the snake until it was well established. The ability to live for long periods of time without food increases the chances of survival in ships' holds, cargo bays of aircraft, and in other conditions that might be encountered when hiding in cargo being moved between islands. The broad range of feeding habits ensures that snakes arriving in new environments will adapt to available lizard, bird, and mammal species and will therefore be likely to successfully colonize the island.

It is probable that several of the problems occurring on Guam would be even more severe or have more devastating consequences on the inhabitants of smaller Pacific Islands with less diverse economic bases than Guam. Further introductions of this snake onto other Pacific Islands will cause consternation among residents and negatively affect commerce, tourism, and government services. After two brown tree snakes were discovered on Oahu, the legislature of the State of Hawaii passed a resolution mandating that the Department of Agriculture Plant Quarantine personnel actively strive to exclude brown tree snakes from entering Hawaii. The Governors of the Commonwealth of the Northern Mariana Islands, Territory of Guam, and the State of Pohnpei have appointed snake task forces to control brown tree snakes and reduce the damages caused by this pest species in the Pacific region. Workshops to inform government authorities and transportation workers about the threat of brown tree snakes have been conducted in the State of Hawaii, in the Republic of Belau, in each of the states of the Federated States of Micronesia, and on three islands in the Commonwealth of the Northern Mariana Islands. All of these governments have at least preliminary contingency plans for excluding snakes and responding to snake sightings.

Future Actions Needed

The ability of territorial and federal agencies to respond to the situation on Guam caused by the introduction and proliferation of the brown tree snake is severely limited by the lack of knowledge about this snake and the control of snake populations in general. The biological information presented in this document may help government agencies to detect snakes, to monitor risks, and to develop plans to prevent colonization. Three primary informational voids exist that will need to be addressed by carefully planned research programs. These are:

1. The biology of the brown tree snake in its native range. This work will focus on predators, population controls, habitat use, reproductive habits, and feeding behavior as a means of determining to the extent possible what controls the snake populations in the native range.

2. The population characteristics of snakes on Guam. Special emphasis is needed on studies of present densities relative to past and present prey bases, habitat use, population trends, movements, and sources of mortality. Information is also needed on the degree of contact with human populations, urban/military areas, cargo destined for other Pacific Islands, and the incidence of snakes arriving to other islands from Guam.

3. Snake control technology. The entire spectrum of technology needed for control of the brown tree snake should be evaluated. Particularly important will be development of appropriate attractants, traps, baits suitable for delivering snake toxicants, environmentally compatible toxicants, and potential biological control measures (parasites, diseases, habitat requirements, and predators). The ability to detect, monitor, capture, kill, or exclude snakes will be important to minimizing the ecological, economic, technical, and human problems caused by snakes on Guam. The same control technologies will also serve in a second objective of minimizing dispersal from Guam to other islands and the eradication of any individuals or populations that may be established at present or in the future.

Baits and Attractants

The brown tree snake is known to use both olfactory and visual cues to locate, evaluate, and capture prey (Chiszar et al. 1988, in press). Brown tree snakes were attracted to traps baited with bird odors in forested areas of Guam (Fritts and Scott 1985; Fritts et al., in press). The potential for developing artificial baits that will attract snakes and be eaten by them is high. Brown tree snakes are known to have eaten (scavenged) substances that were not moving and did not resemble natural prey. One free-ranging snake in Guam was discovered as it consumed canned dog food from a dog's bowl in a residential yard (Fritts and Scott 1985); captive individuals readily consume canned dog food and lumps of hamburger meat mixed with chicken eggs. Pork spare-rib bones (Savidge 1986) and chicken bones (B. Reinhardt, pers. comm.) from picnic litter have been found in the stomachs of brown tree snakes in Guam. Olfactory cues are likely to have stimulated the feeding behavior in each of these cases.

Pheromones (chemical substances used to communicate with other individuals of the same species) are known to be important in allowing males to track and locate suitable mates (Ford and Low 1984). A variety of evidence exists suggesting that large molecules produced as an intermediate step of egg production are deposited in the blood and skin of snakes (Garstka and Crews 1981) and are detectable by other snakes using nasal olfaction and the tongue-vomeronasal complex. The ability to extract, identify, and synthesize substances from the skins of female snakes attractive to other snakes (Schell and Weldon 1985) is a fertile line of control research. Such chemicals may allow snakes to be attracted from large distances and along specific routes (Ford and Low 1984) where other control agents could be employed.

Baits, attractants, and pheromones are needed to: (1) lure snakes to situations where they can be detected, censused, captured, and killed; and (2) stimulate feeding to administer toxicants.

Fumigants and Repellents

Substances which either kill or cause snakes to leave an area are needed to detect snakes, remove them from areas where they pose problems (e.g., cargo, aircraft, ships), and discourage invasion of such areas. Snakes are known to show evasive behaviors to a wide variety of substances including the vapors of para-dichloro-benzene, tear gas, gasoline, halothane, and methoxyflurane. Prolonged exposure to some or all of these chemicals may cause death or immobilization. Snakes are also known to display escape behaviors and evade areas in response to scents of other ophidians known to be snake predators (Weldon 1982). Identification, concentration, and synthesis of the substances producing these behaviors could provide an effective snake repellent with negligible affects on humans or other animals.

Traps

Some information exists on trap efficacy, but considerable opportunity exists to improve traps; to adapt them to differing situations; and to reduce costs, servicing time, and size (Fritts and Scott 1985). Directions for construction and use of a simple snake trap are provided in Appendix 1. Although trapping is not expected to be a principal element of the control program for snakes over large areas, traps may be extremely useful in confined areas, buildings, and artificial habitats. They may also be appropriate in combination with other techniques for areas with low concentrations of snakes, such as recently colonized islands. The recent development of adhesive traps for rodents offers an alternative trapping strategy for snakes in buildings, ships, and aircraft (Figure 9).

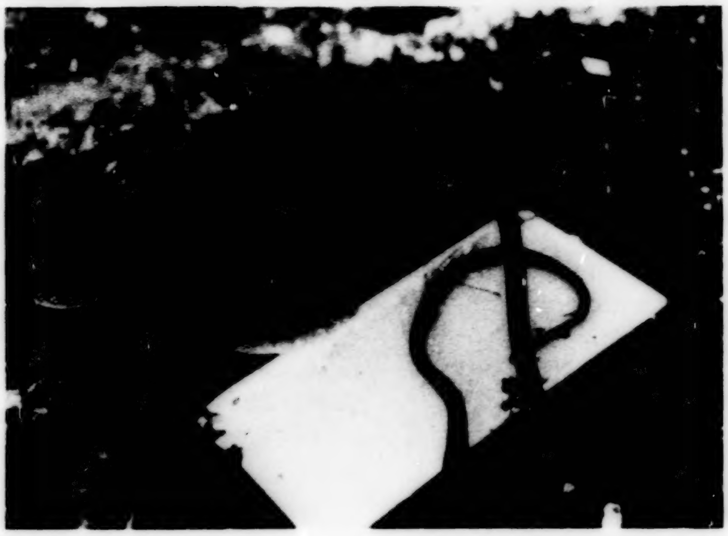


Figure 9. A snake caught on an adhesive trap which had been placed along a wall of a cage housing the snake. This and similar traps are sold commercially for rodent control.

Toxicants

No chemicals are registered for snake control and nearly all substances to which snakes are currently known to be sensitive (e.g., nicotine sulphate, DDT, and aldrin) are known to have effects on a wide variety of biological organisms. However, the possibility exists that a toxicant with minimal secondary hazards could be identified, and that special or emergency registration could be obtained for use in specific situations on Pacific Islands. Even substances with known secondary effects when applied as broadcast pesticides might be suitable if presented under conditions in which such effects could be avoided. In concert with effective attractants or baits, and in special bait stations allowing entry of snakes only, the risk to other fauna and humans may be reduced and the value of such pesticides may justify their use. The Guam Environmental Protection Agency is aware of the snake problem and has offered to consider special requests related to snake control. Although normal registration of toxicants for animal control is a long and costly procedure, the possibility that an effective chemical exists already registered for similar uses may reduce the investment in a toxicant for snakes.

Biological Control

Despite the fame of the more than a dozen species of mongoose known from Africa and Asia as snake predators, in reality these animals are less efficient at controlling snakes than popularly believed (Minton and Minton 1980; Engelmann and Obst 1982). In general, introductions of mongoose to control snakes (West Indies) and rats (Hawaiian Islands) have resulted in the mongoose preying on a wide variety of beneficial animals, causing additional problems rather than alleviating the problems caused by the intended prey. The mongoose is active during the day and is not a proficient climber. Thus it is poorly adapted as a predator of the nocturnally active brown tree snake that is most abundant above the ground in vegetation.

Other snake predators are either as equally nonspecific as the mongoose in their dietary habits or potentially pose other problems (Parker 1963) if they were to be introduced and become established on Guam. Like the brown tree snake, any other introduced animal without effective population controls could become a pest (Engelmann and Obst 1982), and it is often difficult to predict in advance what the extent of such problems will be.

Theoretically, control of the snake population could be done with a virulent disease or parasite, but little information exists on such agents that affect snakes. The research to identify, evaluate, and establish the safety of such control techniques would be costly and would require several years.

Bounty Programs and Commercial Exploitation

The capture of snakes for profit by the residents of Guam is unlikely to have a significant impact on the snake population on Guam. Such efforts would not be concentrated on any one site for long enough to eradicate snakes because as soon as snake density dropped noticeably, efforts would be shifted to other areas where catch per unit effort would be expected to be better. Thus capture for profit would result in cropping snake populations with little chance to significantly reduce snake abundance more than slightly.

An additional problem exists with a control program motivated by commercial exploitation of snakes for meat or skins. Residents of Guam have a relatively high per capita income. Any program lucrative enough to attract a significant participation of Guam's population in the capture and processing of snake products would encourage some opportunists to raise snakes in captivity and even more importantly introduce snakes to other islands with fewer economic opportunities.

The fact remains that snakes are repulsive and frightening to most residents of Guam. Snakes are killed when they are encountered, but few people are willing to go beyond their yards to look for snakes. Thus a bounty program would probably result in the purchase of snakes that would have been killed anyway. The use of traps in the vicinity of residences and poultry houses might reduce damages to pets, poultry, and other domesticated animals but is not likely to significantly improve the survival of forest birds or lower the snake population islandwide (Fritts and Scott 1985).

Any effective control program will require dedicated snake control personnel working in specific areas rather than attempting to maximize the numbers of snakes removed without reference to geographic areas. Nearly one third of the island of Guam is controlled by military commands and much of this area is off limits to most of the civilian population of Guam. Thus large areas where snake control could not be performed by the general population of Guam would remain as sources of snakes capable of dispersing into adjacent areas and therefore diluting any control benefits.

Steps to Control Dispersal

The task of preventing snakes from being carried from Guam to other Pacific Islands is a complex one involving several elements and a diversity of governmental agencies and private companies. The success of any effort to minimize the chance of dispersal will involve active programs on Guam as well as on the islands judged most likely to receive the snake (Appendices 2 and 3).

The degree of threat to any island will depend on the type of cargo and traffic from Guam, the frequency of such shipments, and the specific conditions at the point of disembarkation. Of the islands and island groups considered to be most at risk of receiving the brown tree snake from Guam are the Federated States of Micronesia (Pohnpei, Kosrae, Yap, and Truk), the Republic of Belau, and the Commonwealth of the Northern Mariana Islands (Saipan, Tinian, and Rota). Areas at reduced risk are the Marshall Islands, American Samoa, and other Micronesian Islands (especially Nauru) with less frequent air and ship traffic from Guam.

A 100% effective effort to prevent snakes from leaving Guam and arriving to other islands may not be feasible, but any success in reducing the number of incidents could be important in preventing the establishment of additional populations. The chances of new populations being established depend on the existence of a sufficiently large number of snakes to constitute a reproductive population.

The minimal number of snakes that could establish a population capable of reproducing would be a single female carrying fertilized eggs or carrying sufficient sperm to fertilize a yet to be produced clutch of eggs.

A more likely scenario for a successful colonization would be the arrival of several individuals including both adults and juveniles over a period of time with some individuals dispersing away from the others and others dying due to chance events, but the successful founders would be individuals in habitats close to the point of arrival experiencing high survival. Every individual snake does not constitute a potential colonization, but each one contributes to the overall probability of the successful establishment of an introduced population. Thus patterns of repeated occurrence in specific types of cargo and multiple incidents of snakes arriving to the same port or cargo destination are extremely important to preventing the spread of the brown tree snake problem. The discovery and capture of a single snake are important preliminary steps in the process; but more importantly, the discovery should heighten awareness and continued vigilance for others arriving in the same or similar ways. Search for patterns in arrivals will be the key to identifying the highest risk vectors for the snakes arriving on a new island.

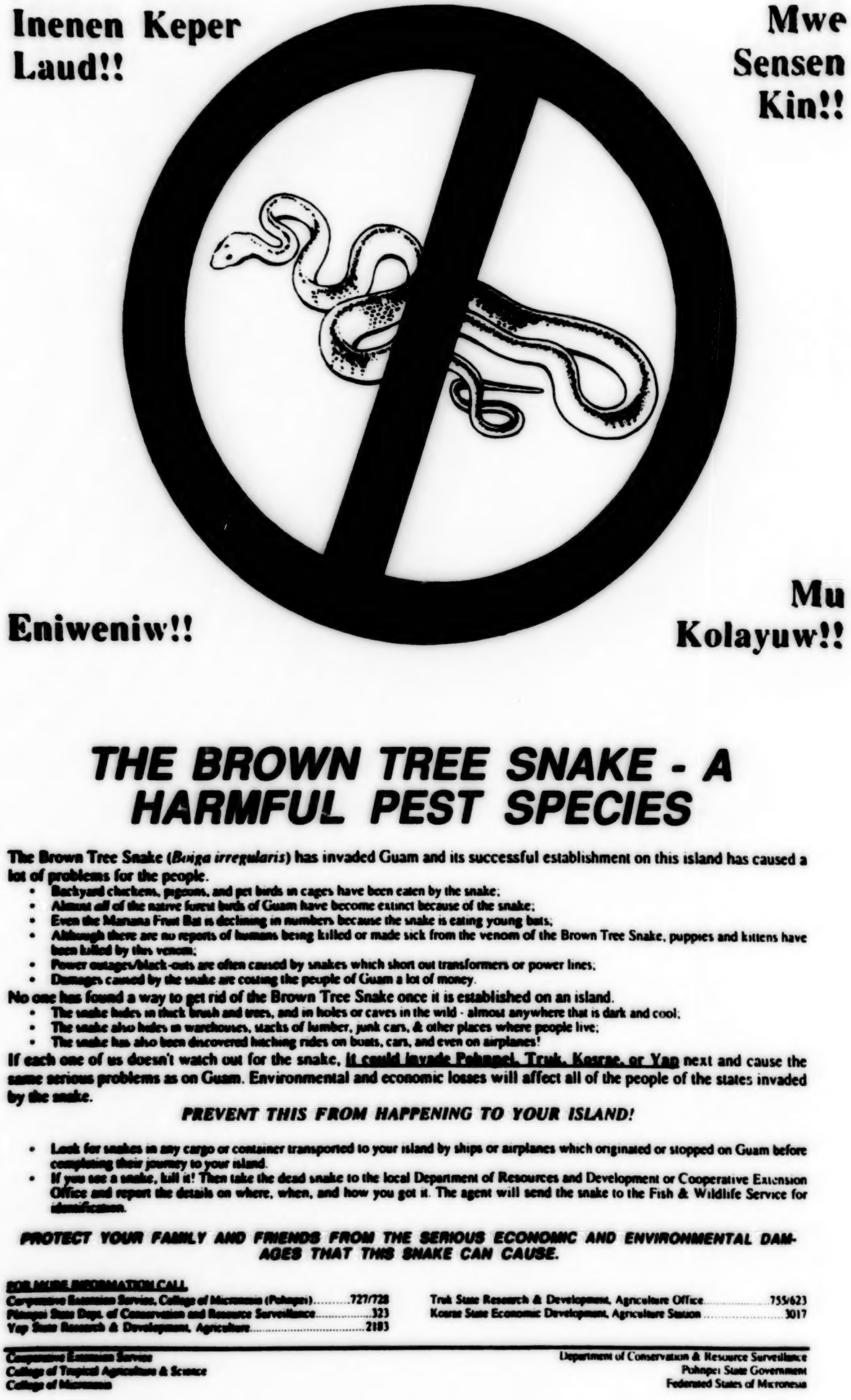
Early detection of newly established populations is critical to any attempt to eradicate or control this snake. Recently arrived snakes will be in the immediate vicinity, whereas dispersal into more isolated habitats will occur as time passes.

The appropriate response to a snake sighting would vary with the circumstances and location. Snakes are commonly encountered in day-to-day activities on Guam, and the sighting of a single individual there may not be important. Conversely, a sighting in cargo recently arrived to Pohnpei, or other islands in the Federated States of Micronesia where large snakes are unknown, would be important, and would justify thorough inspection, written confirmation of the sighting and the circumstances in which it occurred, and evaluation of the ways snakes might be invading such cargo.

Several islands in Palau have native snakes, and it is important that native snakes be distinguished from any sightings of brown tree snakes that might arrive in off-island cargo. The native snakes of Palau are not harmful and should not be killed indiscriminately. However, the sighting of an unfamiliar snake in close proximity to air or ship cargo areas in Palau may justify careful search to capture and identify the snake. On most Pacific Islands a snake sighting not directly associated with cargo or the port areas might be a sign of an already established population, and this type of sighting might justify intensive search for additional specimens. A danger exists that residents of Palau and Guam who are used to seeing snakes may not react to sightings of brown tree snakes or take appropriate measures to reduce the occurrence of introduced snakes on other islands, assuming that the snakes are already present.

Activities on Guam may reduce the numbers and likelihood of snakes leaving Guam in cargo or baggage destined for high risk islands, but the ultimate defense against such an introduction will depend on the efforts of agencies and the entire human population on the islands not desiring this economic and ecological burden. Activities on other islands will require vigilance to detect, capture, and eradicate any snakes that might arrive and therefore reduce the probability of a self-propagating population becoming established.

The starting point for any program aimed at reducing the movements of snakes in ship and air traffic will be informing appropriate governmental agencies and the development of cooperation and communication between the diverse organizations involved in transportation, inspection, and distribution of cargo from off-island. Because most island residents will be unfamiliar with snakes, training of personnel in detecting snakes and responding to sightings will be needed. Educational materials will be needed to inform agency personnel and the general public (Figure 10).


Inenen Keper Laud!!
Mwe Sensen Kin!!
Eniweniw!!
Mu Kolayuw!!

THE BROWN TREE SNAKE - A HARMFUL PEST SPECIES

The Brown Tree Snake (*Boiga irregularis*) has invaded Guam and its successful establishment on this island has caused a lot of problems for the people.

- **Backyard chickens, pigeons, and pet birds in cages have been eaten by the snake;**
- **Almost all of the native forest birds of Guam have become extinct because of the snake;**
- **Even the Mariana Fruit Bat is declining in numbers because the snake is eating young bats;**
- **Although there are no reports of humans being killed or made sick from the venom of the Brown Tree Snake, puppies and kittens have been killed by this venom;**
- **Power outages/black-outs are often caused by snakes which short out transformers or power lines;**
- **Damages caused by the snake are costing the people of Guam a lot of money.**

No one has found a way to get rid of the Brown Tree Snake once it is established on an island.

- **The snake hides in thick brush and trees, and in holes or caves in the wild - almost anywhere that is dark and cool;**
- **The snake also hides in warehouses, stacks of lumber, junk cars, & other places where people live;**
- **The snake has also been discovered hitching rides on boats, cars, and even on airplanes!**

If each one of us doesn't watch out for the snake, it could invade Pohnpei, Truk, Kosrae, or Yap next and cause the same serious problems as on Guam. Environmental and economic losses will affect all of the people of the states invaded by the snake.

PREVENT THIS FROM HAPPENING TO YOUR ISLAND!

- **Look for snakes in any cargo or container transported to your island by ships or airplanes which originated or stopped on Guam before completing their journey to your island.**
- **If you see a snake, kill it! Then take the dead snake to the local Department of Resources and Development or Cooperative Extension Office and report the details on where, when, and how you got it. The agent will send the snake to the Fish & Wildlife Service for identification.**

PROTECT YOUR FAMILY AND FRIENDS FROM THE SERIOUS ECONOMIC AND ENVIRONMENTAL DAMAGES THAT THIS SNAKE CAN CAUSE.

FOR MORE INFORMATION CALL

Cooperative Extension Service, College of Micronesia (Pohnpei)	727/728
Pohnpei State Dept. of Conservation and Resource Surveillance	323
Yap State Research & Development, Agriculture	2183
Truk State Research & Development, Agriculture Office	755/623
Kosrae State Economic Development, Agriculture Station	3017

Cooperative Extension Service
College of Tropical Agriculture & Science
College of Micronesia

Department of Conservation & Resource Surveillance
Pohnpei State Government
Federated States of Micronesia

Figure 10. An example of a public information poster alerting Pacific Island residents and travelers of actions appropriate to preventing snakes from colonizing extralimital islands.

Search for patterns in snake sightings will be the key to identifying the highest risk vectors for the snakes dispersing onto new islands. Early detection of newly established populations is critical to any attempt to eradicate or control this snake. Recently arrived snakes will be in the immediate vicinity, whereas dispersal into more isolated habitats will occur as time passes.

Measures Needed on Guam

Informing the widest possible community of people on Guam of the potential problems that could develop on other islands will be the first step toward reducing this threat. It is important that people on Guam who are used to finding snakes realize that the brown tree snake has not reached other islands and that considerable attempts to prevent its dispersal are worthwhile. Increased awareness of the advantages to preventing the spread of the brown tree snake will contribute to the effort to detect, capture, and exclude snakes from export cargo and from the cargo dispatch areas. By pooling the experience of the diverse community of people and organizations involved in transportation and cargo movements from Guam, the effort to exclude snakes can be focused on those transportation elements that pose the greatest risk of involving snakes. The development of training for military and civilian personnel, preparation of technical information summaries, and the establishment of protocols for detecting and reporting potential problems are needed. At present no procedures exist for either civilian or military personnel responding to the discovery of snakes in cargo destined for other Pacific Islands, and any detection would be a fortuitous event, equally likely to generate an inadequate or overzealous response, while other incidents occur without notice.

Snakes have invaded and are likely to continue to move into urban, suburban, commercial, and military facilities in search of prey, especially the introduced birds, rodents, and lizards that thrive in disturbed and developed habitats. Even though it may not be possible to eliminate snakes entirely, dedicated trapping in these areas may reduce snake abundance locally. Modification of habitats near ports and cargo areas may reduce the occurrence of snakes. Once in developed areas, the snakes are forced to seek daytime retreats in equipment, materials, warehouses, and vehicles. A wide range of food sources and hiding places could exist in maritime ports and airports, and a resident population of snakes constitutes a source of snakes to be dispersed off-island as passive stowaways. Thus detection of snakes, reduction of prey bases, and elimination of permanent hiding places will reduce the snake population.

Measures Needed on Islands at Risk

Activities on other islands will be no less important to preventing colonization of those islands. The first priority will be informing appropriate governmental agencies and the development of cooperation and communication between the diverse organizations involved in transportation, inspection, and distribution of cargo from off-island. Because most island residents will be unfamiliar with snakes, training of personnel in detecting snakes and responding to sightings will be needed.

Risks Due to Military Traffic

The incidents of brown tree snakes in military situations on several extralimital islands point to the danger of the snake dispersing in military transportation routes from Guam. At present the islands most at risk of receiving snakes from military traffic include the Hawaiian Islands, Tinian, Kwajalein, Saipan, and secondarily American Samoa, as well as all islands with military Civic Action Teams supplied from Guam. Tinian may be at special risk because of past and future military use of the North Field area under lease to the Navy. Military traffic from Guam to Okinawa, other Japanese islands, and the Philippines is judged to involve considerably less risk because these areas support native snake faunas, reducing the chances of successful colonizations by the brown tree snake and increasing the probability that native birds would have antipredator behaviors lacking in the native birds of Guam and other small oceanic islands.

The risk posed by military traffic will require especially close coordination of the diverse military units involved in the transportation of equipment, supplies, and personnel from or through Guam. For security reasons and because the number, magnitude, and complexity of military transportation routes worldwide are so great, the detection and elimination of snakes in military traffic should be done by the military, possibly under the control of the Military Customs. The already conspicuous pattern of brown tree snakes being carried to new islands as a result of military traffic justifies a conscientious and thorough approach to this problem by all military commands.

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Appendix 1. Instructions for Making Screen-Wire Snake Traps

The capture of snakes around houses, poultry sheds, and other areas where snakes cause problems can be accomplished using an inexpensive and easily constructed trap made of ordinary aluminum-window screening. The trap works like a fish trap by luring snakes into the trap interior from which they cannot find an exit. In the event that snakes frequent areas around your home, poultry roosts, or other specific areas, you may want to construct one or more traps to capture snakes and merely check the traps daily to remove any captures. The directions for construction and use of the traps are provided below.

Construction of a Simple Snake Trap

The materials needed for two traps include: aluminum screen wire 30 inches wide by 62 inches long, a standard office stapler, staples, scissors to cut screen wire, and gloves to protect your hands during the construction.

Step 1: Cut a piece of screen wire 30 x 23 inches and fold the edges together to form a teardrop-shaped tube 30 inches long (Appendix Figure 1A).

Step 2: Leaving the ends open, hold the edges together and staple at 1-inch intervals along the entire length except for a 6-inch segment near the middle. Fold the stapled edge over, staple again, and round the tube into a cylinder (Appendix Figure 1B). The 6-inch area left unstapled can be unfolded as a means of opening the trap to remove captures.

Step 3: Using a string 7.5 inches in length, draw two circles 15 inches in diameter on the remaining wire (Appendix Figure 1A), cut them out, and cut them into half circles.

Step 4: Each half circle should be folded so that the straight edge is folded into itself and stapled at 1-inch intervals along the edge (Appendix Figure 1C). Fold over the stapled edge to completely close it and flatten the fold to create a cone-shaped piece of screen.

Step 5: Cut off the tip of the cone with scissors to create a hole about 1 to 2 inches in diameter (Appendix Figure 1D). A hole which will accommodate two fingers is ideal.

Step 6: Insert the point of the cone into the cylinder and staple around the edge of the cone and the end of the cylinder at close intervals (Appendix Figure 1E).

Step 7: Insert another cone in opposite end of cylinder and staple as in Step 6. Note, snakes can push on the base of the cone in an attempt to escape, so it is important to have the staples close together with no open spaces remaining.

Step 8: Complete second trap with remaining materials.

The traps are now complete and can be placed in trees, on tops of cages, or in other places where snakes are likely to be found. The traps should be baited with bird odors. The most effective odors to date have been bird droppings (i.e., manure), nest material used by chickens, and chicken feathers. The amount of the bait is not important, but a handful of feathers or nest material or 2-4 tablespoons of chicken manure should be adequate for a 1 to 2-week period. If the trap will be exposed to hard rains it may be necessary to cover the middle section with a piece of plastic (e.g., a piece of a garbage bag) in order to keep the bait from washing away. The plastic can be loosely stapled around the middle section of the trap (Appendix Figure 1F).

The trap should be placed horizontally and can be suspended with string or wire from a tree branch or other appropriate structure.

Once installed, the traps should be checked at 1-2 day intervals. Most captures will be at night, so checking your traps in the morning will reduce the chances that any snakes will escape. The snakes can be removed by unfolding the area left unstapled in the middle of the cylinder and inserting a gloved hand. The trap opening should be closed carefully by refolding the wire at the opening. A large binder clip can be used to temporarily close the opening if necessary. Occasionally, large snakes are able to force the staples at the ends of the trap and escape. Thus, the ends of the trap should be inspected periodically and reinforced when needed.

Appendix Figure 1. Diagram of the construction of a simple snake trap.

A. Cuts on a 30 x 62 inch piece of aluminum window screen sufficient to make two traps.

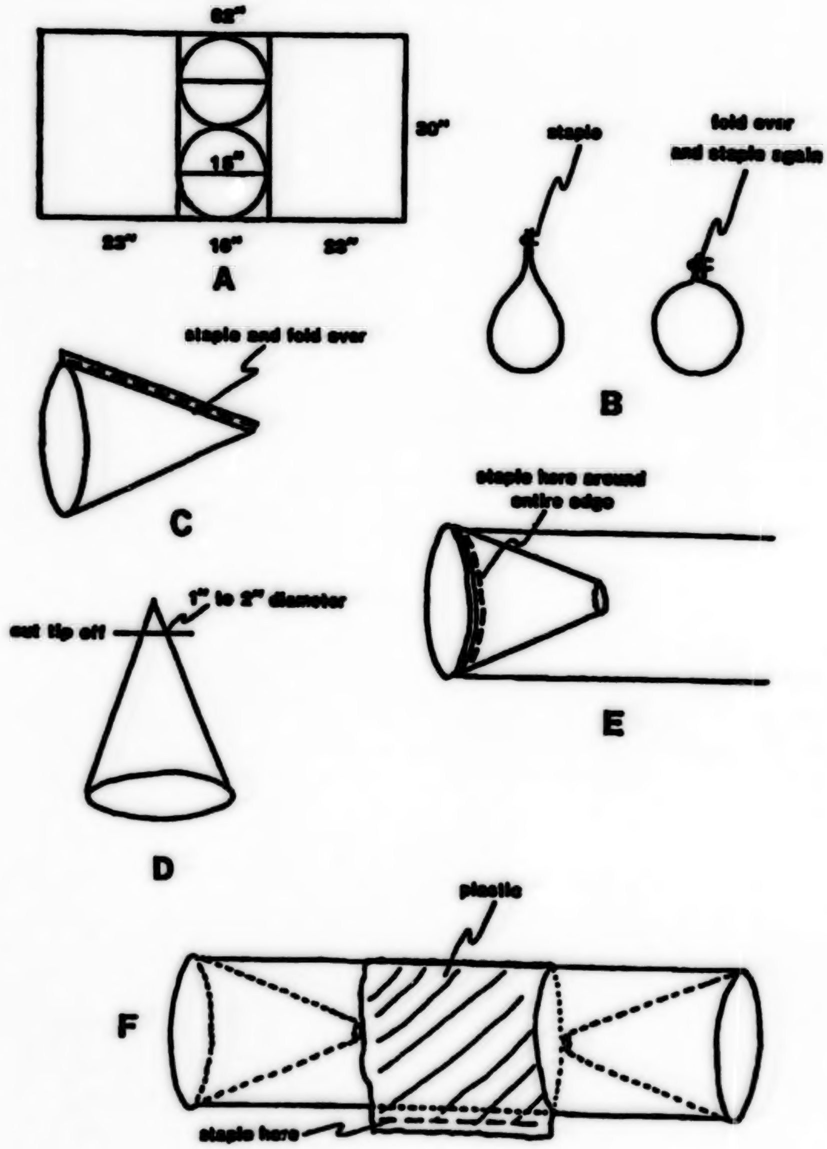
B. Double staple the seam on the wire cylinder, leaving a 6 inch unstapled strip in the middle for access to the snakes.

C. Method of forming funnels from semicircles of wire.

D. Cut off the tip of the funnel to make a 1 to 2-inch entry hole.

E. Method of stapling funnel to cylinder.

F. Cover part of trap with plastic sheeting if necessary to protect the bait.



Appendix 2. A Program to Reduce Snake Dispersal from Guam to Other Islands

A program aimed at reducing the chances of snakes dispersing from Guam to other islands would include the following elements:

1. Review of risks and determination of most probable sources of dispersing snakes.

    a. Passive dispersal in maritime and air traffic.

    b. Deliberate introductions by man for profit, pets, or vandalism.

2. Develop information materials to inform the following groups of people:

    a. Residents of Guam.

    b. All military personnel assigned to bases on Guam and all personnel temporarily assigned on Guam.

    c. Personnel of all agencies involved in inspection of cargo and luggage shipped from Guam and the carriers (cargo and passenger).

    d. Personnel of all agencies involved in inspection of cargo and luggage arriving from Guam to high risk islands (examples include customs, agricultural, health, and security agencies).

    e. Stevedores and airport workers most likely to discover stowaways during loading and unloading.

    f. Wildlife and natural resources personnel most likely to receive reports of snakes discovered on high risk islands.

    g. Employees of companies involved in packing, storing, and moving civilian and military household effects.

    h. Military personnel involved in packing, storing, inspecting, and shipping equipment, supplies, and vehicles.

    i. Military customs.

    j. Military personnel assigned to missions that require frequent travel to other Pacific Islands.

3. Reduce density of snakes in and around cargo dispatch areas and other transportation facilities on Guam.

4. Develop methods of detection and capture in cargo areas.

5. Develop procedure for reporting sightings, identifying snakes, responding to reports, and analyzing patterns of occurrences.

6. Use data from 5 above to focus control efforts and maximize effectiveness of program.

7. Identify islands most likely to receive snakes from Guam, criteria to include:

    a. Number of persons traveling to island from Guam.

    b. Amount of cargo shipped to island from Guam.

    c. Likelihood of snakes being successful on island.

    d. Extent of damage that might occur if snakes do become established.

    e. Number of household moves to island from or through Guam.

    f. Number of maritime and air arrivals from Guam, amount of time spent there, and opportunities for snakes to actively or passively disembark.

8. Inherent in 7 is a need for analyzing major traffic patterns from Guam and attempting to identify high risk islands on which most activities will be focused.

Appendix 3. A Strategic Plan for Controlling and Eradicating Introduced Populations of the Brown Tree Snake in the Pacific Islands

Prepared by: Ernest Kosaka, Field Supervisor, Environmental Services, U.S. Fish and Wildlife Service, Pacific Islands Area Office, Honolulu, HI, 96850.

This strategic step-down plan was developed through input from agencies involved in attempting to control the brown tree snake (*Boiga irregularis*) on Guam and those who are striving to prevent invasion of this pest species to their jurisdictions. The format follows guidelines in Resource Publication 123 (Phenicie and Lyons. 1973. Tactical planning in fish and wildlife management and research. Federal Aid Division, U.S. Bureau of Sport Fisheries and Wildlife, Washington, DC). The strategic step-down plan is not an approved Fish and Wildlife Service document. Rather, it is a tool which describes reasonable actions which need to be implemented, and the order in which they have to be implemented, to control and eradicate introduced populations of the brown tree snake in the Pacific Islands.

1. Primary Objective: Controlling and eradicating introduced populations of the brown tree snake in the Pacific Islands.

    11. Conduct biological studies of the snake on Guam and its native range to obtain data that will enhance control and eradication efforts.

        111. Conduct life history studies of the snake on Guam.

            1111. Conduct habitat use studies and to determine optimum deployment patterns and physical design of traps/trapping devices.

                11111. Determine habitat preferences of the snake to narrow focus of capture and control efforts.

                11112. Determine optimum physical design of traps/trapping devices based on habitat preferences.

            1112. Conduct reproduction studies to improve understanding of population dynamics.

            1113. Conduct food habits studies to develop the most effective bait(s) for control programs.

                11131. Conduct experiments with attractants (pheromones) for use with and without baits.

                11132. Conduct experiments on bait formulations to develop long-lasting, maintenance free baits.

                11133. Conduct field tests to determine most effective bait(s).

            1114. Conduct movement studies to determine the most effective deployment of snake capture and control devices.

11141. Determine optimum deployment for traps and trapping devices based on daily and seasonal movement patterns.

1115. Develop monitoring (census) technique to periodically determine status and distribution of the snake on Guam.

112. Conduct biological studies of the snake in its native range to determine natural limiting factors which are not in evidence on Guam.

1121. Determine whether a disease(s) offers a potential means for controlling the species on Guam.

1122. Determine whether a parasite(s) offers a potential means for controlling the species on Guam.

1123. Determine whether a natural predator(s) offers a potential means for controlling the species on Guam.

12. Develop new and improved control and eradication techniques.

121. Develop a snake inspection protocol for detecting and eliminating the snake from all surface and air cargo out-bound from Guam.

1211. Develop a snake inspection protocol for use by commercial exporters/shippers focused on preventing invasion from high-risk-commercial cargoes.

1212. Develop a snake inspection protocol for use by military personnel focused on preventing dispersal from military cargoes.

122. Investigate chemical compounds, physical and electrical barriers for eliminating or controlling snakes.

1221. Develop a snake toxicant for delivery in bait(s).

12211. Screen potential toxicants under laboratory conditions.

12212. Field test candidate toxicants.

12213. License toxicant/bait combination(s) as appropriate for use in controlling snakes.

1222. Develop a fumigant to control snakes in containerized cargo or other confined situations.

12221. Screen potential fumigants under laboratory conditions.

12222. Field test candidate fumigants.

12223. License fumigant(s) for use in containerized cargo or other confined situations.

1223. Develop chemical repellents for controlling snakes in localized areas.

12231. Screen potential repellent(s) under laboratory conditions.

12232. Field test candidate repellent(s).

12233. License repellent(s) for use in port/storage areas, etc.

1224. Investigate physical and electrical barriers for controlling snakes in limited areas.

12241. Design potential physical and electrical barriers.

12242. Conduct laboratory and field tests to select most promising control techniques.

12243. Select and implement the most promising designs for physical and electrical barriers.

1225. Conduct a pilot field project using the most effective new control and eradication techniques developed to determine whether snakes can be removed from a reasonable area of forest.

13. Implement improved snake control and eradication programs.

131. Develop procedures and implement new techniques for controlling and eliminating snake populations in areas from which they are likely to disperse and invade other islands.

1311. Coordinate biological data with new data on control techniques to control and/or eradicate from cargo/port areas.

1312. Coordinate biological data with new data on control techniques to eradicate snakes from containerized cargo or other confined situations.

132. Collect information from commercial and military shippers to determine high risk dispersal cargoes and destinations.

1321. Collect snake incident data for all cargo outbound from Guam.

1322. Collect snake incident data for all cargo inbound from Guam.

1323. Evaluate incident data to refine high-risk-dispersal cargoes and destinations.

14. Inform and educate private, public, and military sectors on the serious economic and environmental consequences of the snake and Guam and the necessity for preventing invasion and colonization of this snake in other political jurisdictions.

141. Provide special training for Guam based personnel on detecting and eliminating the snake from *all* surface and air cargo outbound from Guam.

142. Assist with development of Emergency Snake Control Teams in the Pacific jurisdictions at risk to invasion by the snake.

1421. Provide special training for Emergency Snake Control Teams on detecting and eliminating the snake from *all* surface and air cargo arriving from Guam.

15. Coordination and administration of control and eradication programs throughout the Pacific.

151. Develop a mechanism for facilitating coordination of control and eradication programs throughout the Pacific (Memorandum of Understanding, Cooperative Agreement, etc).

152. Coordinate and disseminate information provided by cooperating agencies for controlling and eradicating introduced populations of the brown tree snake in their political jurisdictions.

1521. Evaluate data provided by all cooperating researchers and disseminate information on new/improved control and eradication techniques.

1522. Develop a newsletter for disseminating information among cooperating and concerned agencies.

15221. Send newsletter to all Emergency Snake Control Teams throughout the Pacific.

15222. Send newsletter to Governors of all Pacific Island jurisdictions.

15223. Send newsletter to agencies and individuals who should be made aware of snake-caused problems.

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16. Abstract (Limit: 200 words)

Today, much of the native bird fauna of Guam is extirpated from the island and, with few exceptions, the native and introduced species that remain are on the verge of disappearing. These island-wide extinctions are primarily due to a single factor: the introduction of an exotic snake, the brown tree snake (*Boiga irregularis*). As the snake population grew, snakes also began causing interruptions to electrical equipment when they caused electrical shorts and major power failures by climbing on high voltage lines. This frequent problem hampers nearly every facet of civilian and military activities on Guam and constitutes a severe economic burden of millions of dollars in damages to equipment and loss of work productivity for the island. The snakes also constitute a significant agricultural pest around poultry, domesticated birds, other farm animals, and pets. The danger now exists that the brown tree snake will be transported to other Pacific islands where similar "naive" bird communities will be equally vulnerable to extinction and where similar technical and economic problems could develop as a result of uncontrolled snake populations. The purpose of this report is to summarize the biological information available on the brown tree snake; to inform wildlife, agriculture, customs, and other responsible agencies in Pacific Island governments of the danger that exists; and to outline steps necessary to prevent dispersal and establishment of introduced snake populations on Pacific Islands.

17. Document Analysis a. Descriptors
Ecology
Pest control
Reptiles
Snakes

b. Identifiers/Open-Ended Terms
Brown tree snake
Boiga irregularis
Guam
Pacific Islands

c. COSATI Field/Group

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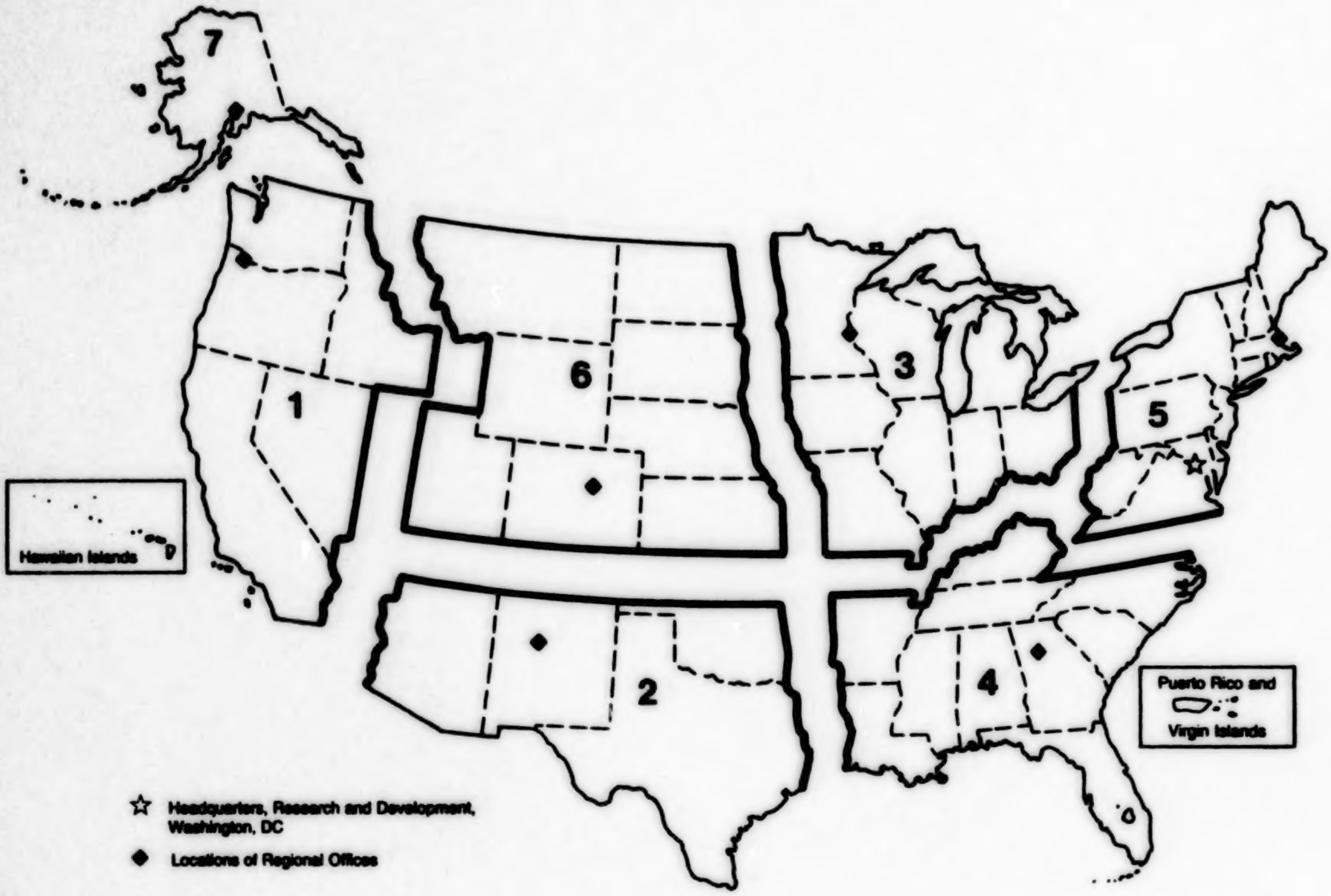
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Hawaiian Islands
Puerto Rico and Virgin Islands
☆ Headquarters, Research and Development, Washington, DC
◆ Locations of Regional Offices

REGION 1
Regional Director
U.S. Fish and Wildlife Service
Lloyd Five Hundred Building, Suite 1692
500 N.E. Multnomah Street
Portland, Oregon 97232

REGION 2
Regional Director
U.S. Fish and Wildlife Service
P.O. Box 1306
Albuquerque, New Mexico 87103

REGION 3
Regional Director
U.S. Fish and Wildlife Service
Federal Building, Fort Snelling
Twin Cities, Minnesota 55111

REGION 4
Regional Director
U.S. Fish and Wildlife Service
Richard B. Russell Building
75 Spring Street, S.W.
Atlanta, Georgia 30303

REGION 5
Regional Director
U.S. Fish and Wildlife Service
One Gateway Center
Newton Corner, Massachusetts 02158

REGION 6
Regional Director
U.S. Fish and Wildlife Service
P.O. Box 25486
Denver Federal Center
Denver, Colorado 80225

REGION 7
Regional Director
U.S. Fish and Wildlife Service
1011 E. Tudor Road
Anchorage, Alaska 99503

END

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